Authors' Response to Reviews of

Brief communication: The hidden labyrinth: Deep groundwater in Wright Valley, Antarctica

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Cryosphere

RC: ***Reviewers' Comment***, AR: Authors' Response

1. Reviewer #2

RC: *I read the paper with interest and have just a few suggestions that the authors may or may not want to include depending on scope. I don't have expertise in the resistivity analysis, so I have no comments on that.*

RC: *The article talks a lot about the connectivity between DJP and Vanda, but an equally intriguing question is the ultimate origin of the DJP brine. This is mentioned in passing, but worth emphasizing more. Harris and Cartwright hypothesized that the brine is ultimately sourced from beneath the East Antarctic Ice Sheet i.e. west of DJP and through the Labyrinth. Is there any evidence for this from the resistivity data? A related question is if the DJP brine extends beneath the 'rock glacier'. It looks like west of DJP there is a low resistivity band at depth extending under the 'rock glacier', and very low values at the extreme that look like a numerical artifact.*

AR: Intriguing question indeed! From our data we can't draw any conclusions on the source of the brine. In all of our electromagnetic surveying west of Don Juan Pond, which includes ground-based measurements on top of the rock glacier, and one survey in the Labryinth (which was incredibly difficult given the terrain), we found highly resistive material in the top few hundred meters. However, it is possible, and perhaps even likely that the groundwater sourced from the East Antarctic Ice Sheet would be much deeper than this.

AR: As noted in Foley et al. (2019) [https://www.mdpi.com/2306-5338/6/2/54/htm] "In contrast to West Antarctica, interior East Antarctica is predicted to have overall lower basal melting and is largely surround by zones of net freezing near the coasts where the ice is thin but surface temperatures are cold [33]. This 'confining ring' of cold-based ice sheet margin helps to cryoconcentrate groundwater before it reaches the coast (Foley Figure 3). Thus, a low flux, high concentration groundwater scenario may be representative of much of coastal East Antarctica".

RC: *The DJP transect also shows an interesting, vertical low conductivity feature to the E of DJP. E of DJP the elevation along the valley floor rises and then plateaus along a series of small basins. The first basin you encounter holds VXE-6 pond, which is typically dry at the surface but shallow groundwater occurs. This pond has a high $CaCl_2$ content like Lake Vanda, but also high nitrate indicating considerable surface inputs. None of the other ponds have $CaCl_2$. Cartwright and Harris analyzed this pond, and we recently analyzed it in Toner et al. 2022 (also discusses the mixing between NO_3-rich and $CaCl_2$-rich endmembers). I suspect that wind alone can't explain the $CaCl_2$ in this pond; otherwise, why aren't other ponds similarly enriched? The resistivity data seems to suggest a connection between DJP and VXE-6, which would make sense. This would also put the DJP brine on the right path to connecting Lake Vanda, although the data can't show this. Too bad the flight line didn't extend to Lake Vanda!*

AR: This is fascinating, and we agree that the pond chemistry aligns well with the AEM survey east of DJP. The flight line and additional ground-based surveys did cover the a South Fork transect between Lake Vanda and DJP, but no signal was picked up. So any connection must be deeper than our penetration depth (appox. 500 m).

RC: *We recently published a paper on DJP and surrounding soils and groundwaters (https://www.sciencedirect.com /science/article/abs/pii/S0012821X22002187). One of the findings of the paper was that CaCl2 brine/salts like DJP infuse the Dolerite bedrock up to 200 m above the pond surface. The argument is that salt composition of the dolerite bedrock is so DJP like and different from surrounding soils, that inputs from wind alone can't explain the chemistry (you'd get mixing from nitrate-rich soils if deposited from wind), it must be primary. This supports a much stronger association between the DJP brine and the Ferrar Dolerite than previously thought. This suggests that you might "follow the Dolerite" to understand where the DJP groundwater is going. Might be interesting to include discussion about where the Dolerite is going, perhaps inferred from the strike/dip of the unit.*

AR: It's a great paper and nicely timed to support our results. Thank you for pointing out all of the connections. We will add more discussion on the potential connection between hydrogeological pathways and the Ferrar Dolerite. Unfortunately, we can't say much about the subsurface geology beyond the McKelvey and Webb paper cited in Toner et al. 2022.

RC: *Line 90: The conductivity of salt solutions depends on concentration and composition, and the conductivity decreases at very high concentrations for CaCl2. Could the low conductivity be explained in this way? Also, is the conductivity of CaCl2 different from equivalent ionic strength NaCl solutions. Would the porosity of the sediments and groundwater affect the result? Just wondering if the relatively low conductivity in DJP could be explained more easily.*

AR: Correct, the conductivity of $CaCl_2$ is greater than the conductivity of an equivalent mass of NaCl. See https://www.researchgate.net/publication/280325585. Also for $CaCl_2$, the relationship between concentration (g/L) and specific conductance (mS/cm), is parabolic, with a maximum SpC of approx. 200 mS/cm at 300 g/L. Beyond 300 g/L, specific conductance decreases [see https://escholarship.org/content/qt5v01s3c6/qt5v01s3c6.pdf].

AR: These two properties combined are relevant for thinking about the absolute relationship between inferred conductivity and brine composition. However, I believe the explanation of 1 ohm-m over DJP is still best explained by realizing that the top bin is a combination of a thin brine pool overlaying brine saturated sediments. As shown in Figure 2 from Mikucki et al (2017) [https://www.nature.com/articles/ncomms7831], brine saturated sediments would result in a higher resitivity than pure brine. This was applied to the calculation of brine porosity in Dugan et al. (2014) [https://agupubs-onlinelibrary-wiley-com/doi/full/10.1002/2014GL062431], where we found the resistivity minimum of 1.3 ohm-m indicated that only a fraction of the subsurface volume consists of the highly concentrated 0.15 ohm-m brine observed in the drill holes.